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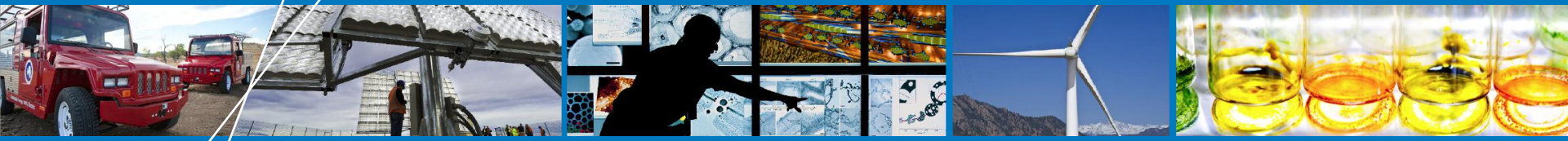
Eastern Renewable Generation Integration Study



March 20, 2013

Project Sponsors

- **This project is made possible by the Department of Energy's:**
  - Offices of Energy Efficiency and Renewable Energy
    - Wind and Water Power Program
    - Solar Energy Technologies Program
  - Office of Electricity Delivery and Energy Reliability
    - National Electricity Delivery Division

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NREL

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- Sundar Venkataraman, GE
- Bob Zavadil, Enernex Corp

What is ERGIS?

Operational Impact Study of High Wind and Solar

- **Eastern Interconnection**
  - Production cost simulation
  - 2020 Study Year
- **High Renewable Penetration**
  - 20-25% wind and 5-10% solar
- **Analytical Framework**
  - PLEXOS production-cost model
  - Hourly and sub-hourly analysis
- **Timeline**
  - Final report due in 2015

Operational Areas of Interest

- **Reserves**
  - Types
  - Quantities
  - Sharing
- **Commitment and Dispatch**
  - Day-ahead
  - 4-hour-ahead
  - Real-time
- **Interchange Efficiency**
  - 1-hour
  - 15-minute
  - 5-minute

Housekeeping

- **Presentation covers lots of material**
- **Brief discussion after each section**
  - 3-5 minutes
- **Working Groups**
  - Wind and solar profiles
  - Thermal and hydro generation characteristics
  - Transmission modeling
  - Thermal fleet expansion and retirements
  - Reserves analysis
  - Others?

Study Limitations

- **We lack:**
  - Bilateral power purchase and other contractual agreement data
  - Detailed operational constraints and/or complete unit specific data in the generation models
  - Capability to simultaneously model different dispatch intervals in different balancing authority areas
- **Uncertainties:**
  - Future cooperation and/or subhourly dispatch across the interconnection
  - The amount and location of variable generation
  - Transmission system additions
  - Generation additions and retirements
  - Gas and coal prices

How are we going to do this?

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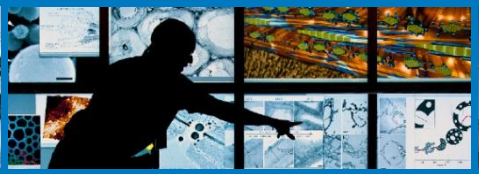
Scenario Development

The Scenarios

- **Three scenarios with different wind and solar resources**
  - Base Case
  - Regional Scenario
  - National Scenario
- **Developed with TRC input last year**

Base Case

- **Similar to EIPC**
  - Based on state retail load for wind and solar
  - All existing wind plants in non-RPS states are included
  - All RPS requirements are met, but not necessarily with in-state resources (e.g. Connecticut)
  - Only wind and solar resources are count towards renewable penetration levels, i.e. not hydro and biomass.
  - RPS=existing + queue + RPS needs
  - Penetration levels
    - 15% Wind
    - 0.25% Solar

Base Case Wind and Solar

* Total penetration is % of energy

	Onshore Capacity (MW)	Onshore Energy (GWh)	Onshore Pen.	Offshore Capacity (MW)	Offshore Energy (GWh)	Offshore Pen.	Total Capacity (MW)	Total Energy (GWh)	Total Pen.
CT	1,045	2,871	8%	920	2,549	7%	1,965	5,420	15%
DE	417	1,036	10%	0	0	0%	417	1,036	10%
IA	8,582	30,791	72%	0	0	0%	8,582	30,791	72%
IL	7,031	24,013	16%	0	0	0%	7,031	24,013	16%
IN	2,225	7,266	6%	0	0	0%	2,225	7,266	6%
KS	4,989	19,005	42%	0	0	0%	4,989	19,005	42%
MA	1,937	6,122	10%	1,000	4,063	6%	2,937	10,184	16%
MD	734	2,217	4%	0	0	0%	734	2,217	4%
ME	450	1,345	10%	0	0	0%	450	1,345	10%
MI	3,178	10,824	7%	1,300	4,291	3%	4,478	15,116	10%
MN	9,393	34,517	45%	0	0	0%	9,393	34,517	45%
MO	2,429	8,535	7%	0	0	0%	2,429	8,535	7%
NC	860	2,581	2%	3,000	10,170	8%	3,860	12,750	10%
ND	4,788	17,485	123%	0	0	0%	4,788	17,485	123%
NE	6,108	22,457	88%	0	0	0%	6,108	22,457	88%
NH	307	1,026	10%	0	0	0%	307	1,026	10%
NJ	423	935	1%	4,000	14,068	14%	4,423	15,003	15%
NY	8,379	28,873	18%	2,620	9,262	6%	10,999	38,135	23%
OH	2,814	8,865	5%	1,020	3,342	2%	3,834	12,207	7%
OK	8,264	31,272	42%	0	0	0%	8,264	31,272	42%
PA	1,214	3,494	2%	0	0	0%	1,214	3,494	2%
RI	242	637	5%	400	1,448	11%	642	2,086	16%
SD	3,197	11,189	12%	0	0	0%	3,197	11,189	12%
TN	100	340	0%	0	0	0%	100	340	0%
TX	7,541	29,465	38%	0	0	0%	7,541	29,465	38%
VA	1,103	3,363	2%	0	0	0%	1,103	3,363	2%
VT	135	491	6%	0	0	0%	135	491	6%
WI	2,044	6,970	9%	640	2,125	3%	2,684	9,095	12%
WV	1,325	4,153	9%	0	0	0%	1,325	4,153	9%

Wind and Solar Scenarios

- **Scenario 1: Regional Resource**
  - 20% Wind
  - 10% Solar
- **Scenario 2: National Resource**
  - 25% Wind
  - 5% Solar

Wind and Solar Capacity Expansion

- **Regional Energy Deployment System (ReEDS)**
  - Long-term capacity-expansion model
  - Aims to minimize total system costs
    - Constraints include: transmission, load, reserves
  - Multi-regional (356 wind/solar resource regions, 134 balancing areas)
  - Temporal resolution: 17 time slices in each year
  - Identifies energy requirement for ReEDS region
  - See interim report

Wind and Solar Minimum Targets

Macro Area	Wind Target	Onshore Wind Target	Offshore Wind Target	Solar Target	Distributed Solar (Rooftop)	Utility Scale PV
FRCC	0%	0%	0%	30%	12%	18%
ISONE	25%	20%	5%	5%	2%	3%
MISO	25%	22.5%	2.5%	5%	2%	3%
NYISO	25%	20%	5%	5%	2%	3%
PJM	25%	15%	10%	5%	2%	3%
SERC w/o VACAR	0%	0%	0%	15%	6%	9%
SPP	25%	25%	0%	5%	2%	3%
VACAR	15%	2.5%	12.5%	15%	6%	9%

A Few Notes

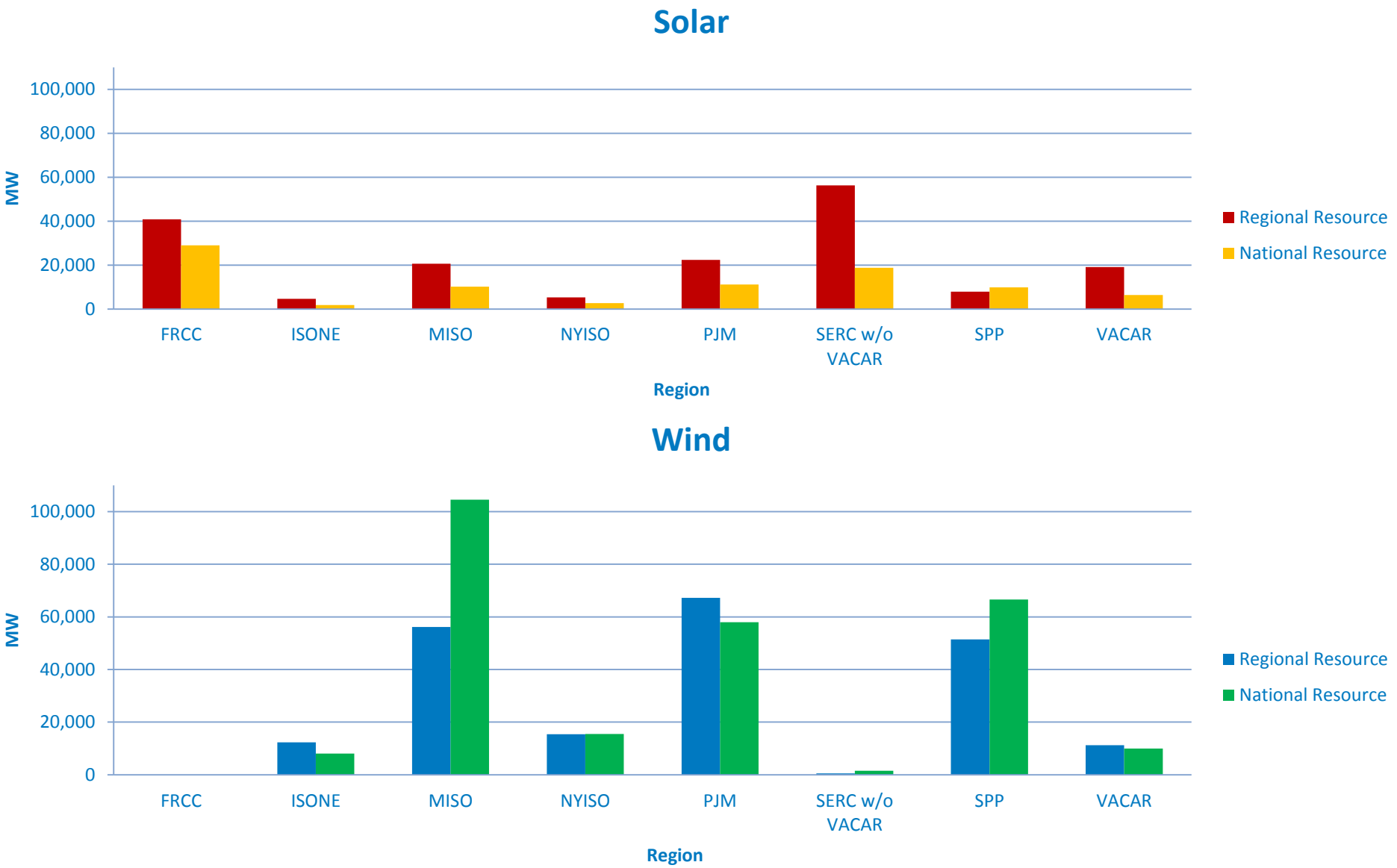
- **Regional Targets**
  - 25% wind
    - 20% onshore and 5% offshore
  - 5% solar PV
    - 2% rooftop and the rest utility
  - VACAR and SERC
    - VACAR has lots of offshore potential
    - NREL data indicates low wind potential in SERC
      - 15% from SPP wind, consistent with SPP Wind Int. Study
- **National Targets**
  - Similar to regional
  - Best generation resources are used to meet targets
  - Minimum solar targets were set to assure rooftop PV

What are the expansion results?

Wind and Solar Maps

- See html files
- Disclaimer: Markers on these maps do not represent individual plants. They represent capacity, and are centered on grid cells used to develop profiles. Do not assume the markers represents the exact location of a plant.

Wind and Solar Capacity



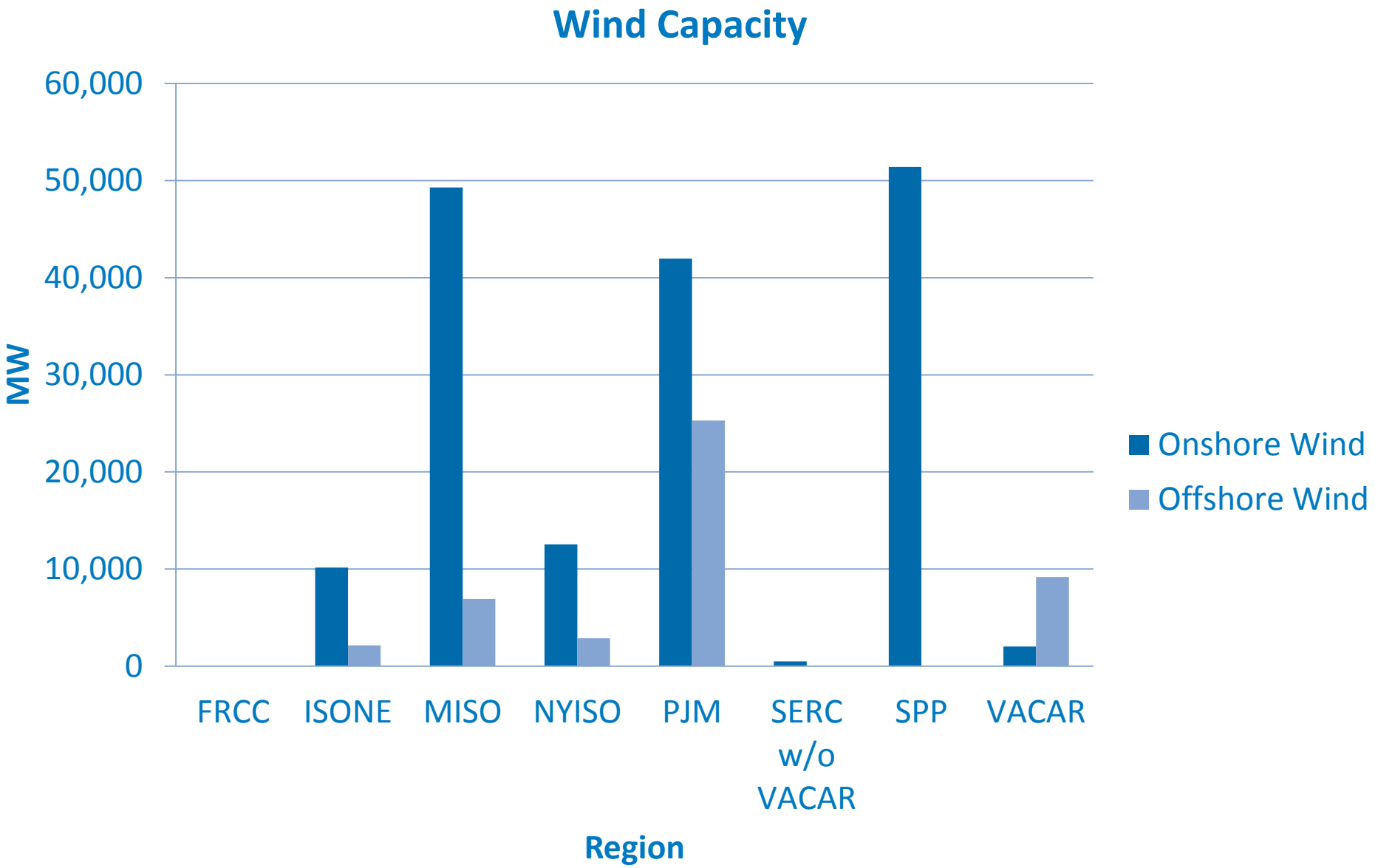
Regional Scenario

Macro Region	Capacity (MW)		Energy (GWh)			Penetration (%)		
	Wind	Solar	Wind	Solar	Load	Wind	Solar	Total
FRCC	0	40,867	0	79,756	265,852	0%	30%	30%
ISONE	12,294	4,612	35,676	7,135	142,702	25%	5%	30%
MISO	56,197	20,616	171,562	34,221	684,420	25%	5%	30%
NYISO	15,399	5,292	41,014	8,203	164,056	25%	5%	30%
PJM	67,252	22,339	184,682	36,936	738,729	25%	5%	30%
SERC w/o VACAR	487	56,303	1,282	97,376	649,174	0%	15%	15%
SPP	51,413	7,905	169,661	14,457	289,139	59%	5%	64%
VACAR	11,200	19,129	33,234	33,234	221,557	15%	15%	30%
Total	214,243	177,063	637,110	311,318	3,155,630	20%	10%	30%

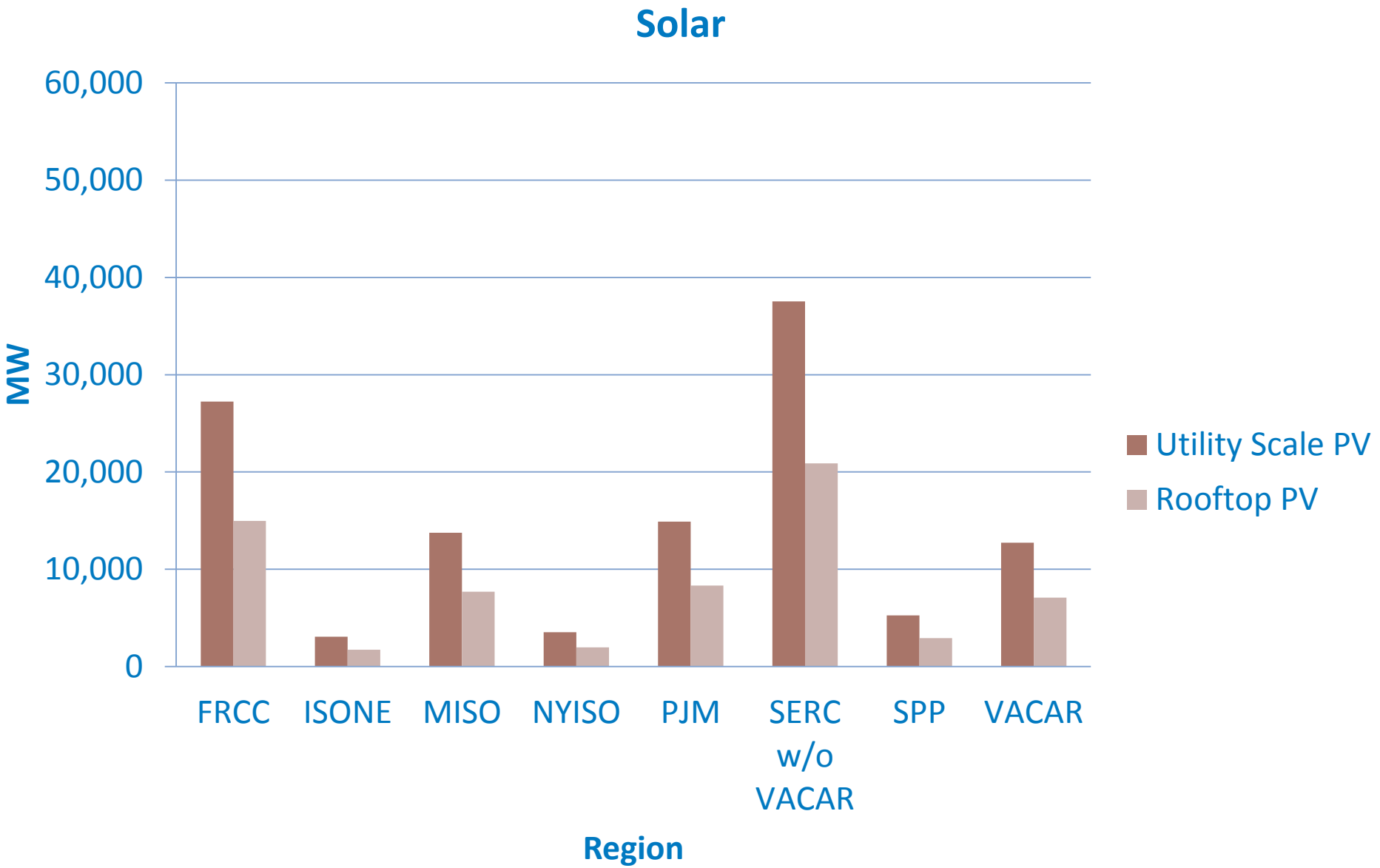
National Scenario

Macro Region	Capacity (MW)		Energy (GWh)			Penetration (%)		
	Wind	Solar	Wind	Solar	Load	Wind	Solar	Total
FRCC	0	28,987	0	56,878	265,852	0%	21%	21%
ISONE	8,053	1,850	24,237	2,854	142,702	17%	2%	19%
MISO	104,488	10,230	307,989	17,110	684,420	45%	3%	47%
NYISO	15,522	2,646	41,335	4,101	164,056	25%	2%	28%
PJM	57,996	11,201	156,986	18,468	738,729	21%	3%	24%
SERC w/o VACAR	1,498	18,771	3,854	32,459	649,174	1%	5%	6%
SPP	66,602	9,839	219,746	20,806	289,139	76%	7%	83%
VACAR	9,968	6,398	28,789	11,078	221,557	13%	5%	18%
Total	264,126	89,922	782,935	163,754	3,155,629	25%	5%	30%

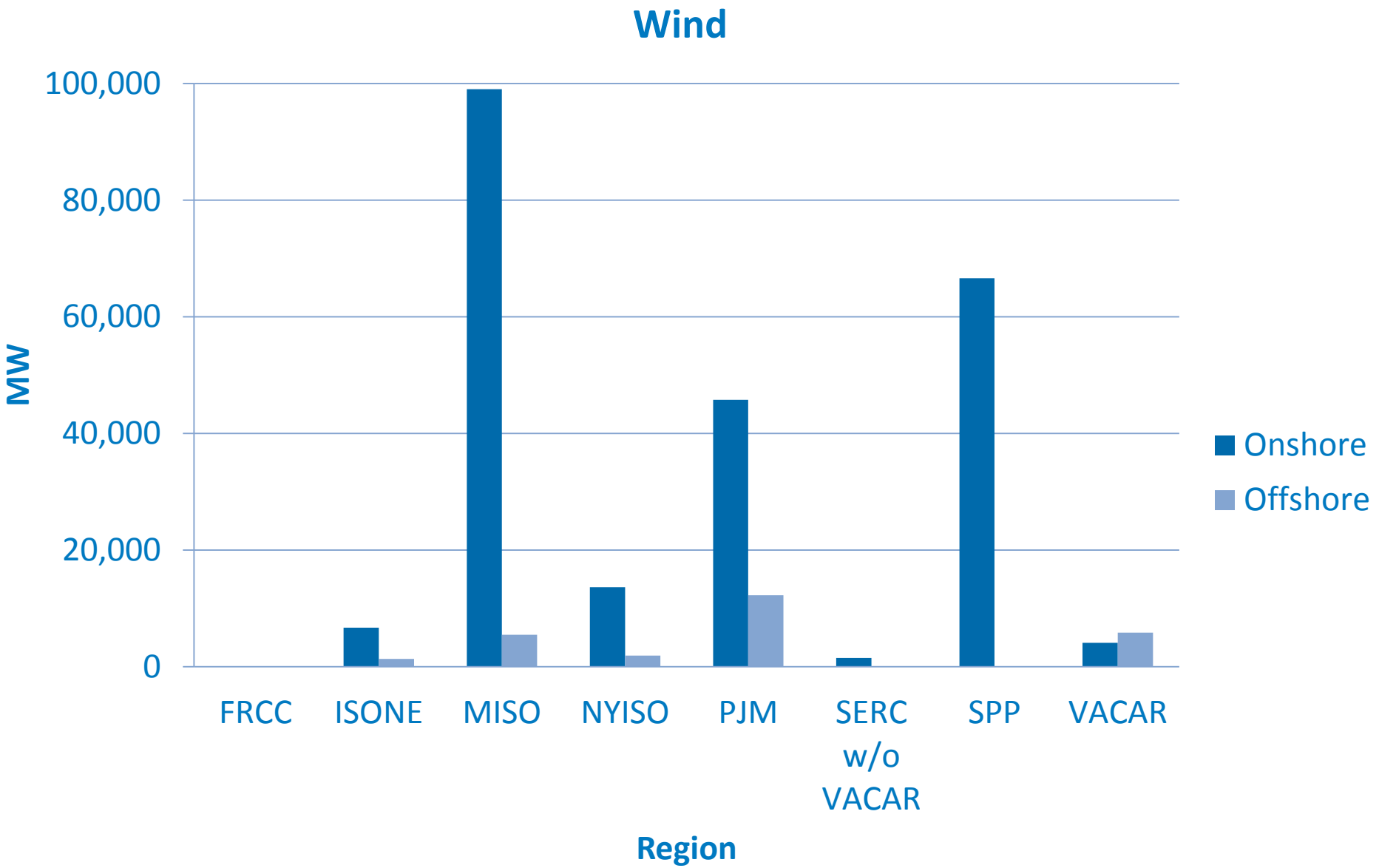
Regional Scenario



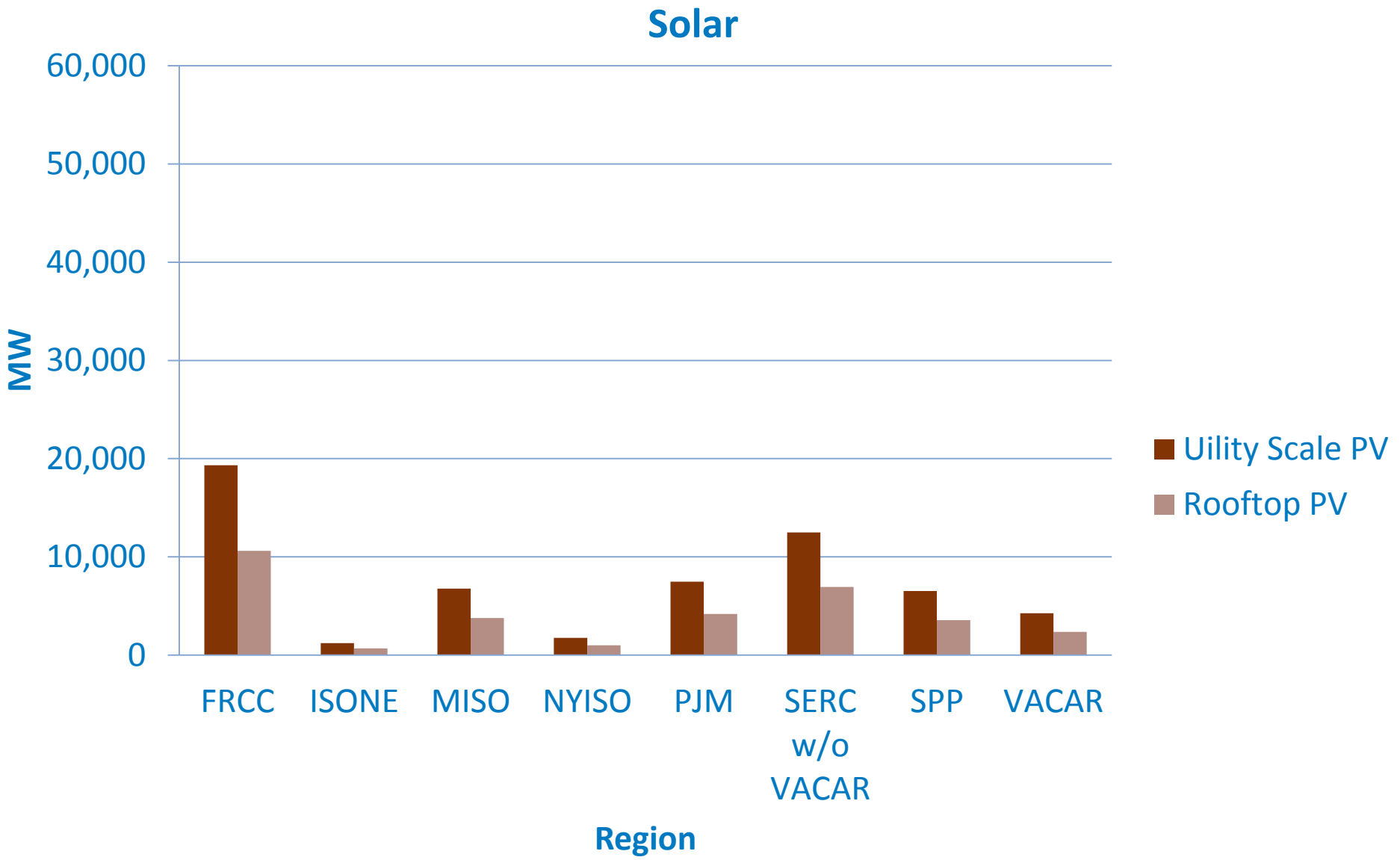
Regional Scenario



National Scenario *note scale change



National Scenario



Rest of Fleet?

- **Working group**
  - Use ReEDS analysis?
  - Assume only gas combined cycle?
  - What about retirements?

Discussion: Scenarios

What are the generation characteristics?

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Wind and Solar Profiles

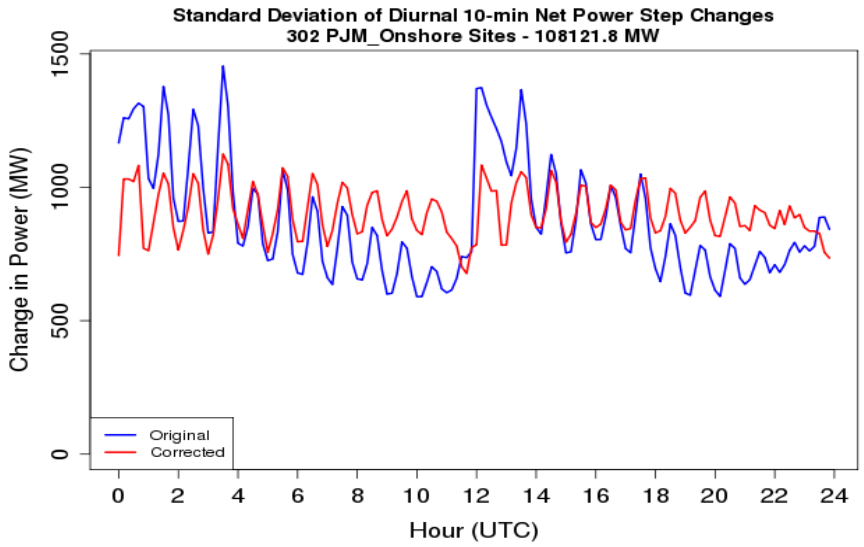



Wind Data

- **Wind dataset inherited from the EWITS**
  - Developed by AWS TruePower
  - Dataset developed using numerical forecasting models performing hindcasts based on historical data
  - 1325 onshore sites of various plant sizes with 580 GW of capacity and approximately 100 GW of offshore
  - 10 minute ‘actuals’ with hourly forecasts at several horizons
  - 3 years of data, 2004 - 2006

2012 Dataset Update

- Modeling technique lead to a variability anomaly every 12 hours
- Identified independently by ERGIS and PJM integration study
- AWST applied statistical corrections to alleviate
- Updated power curves and wind maps used



Wind Site Selection

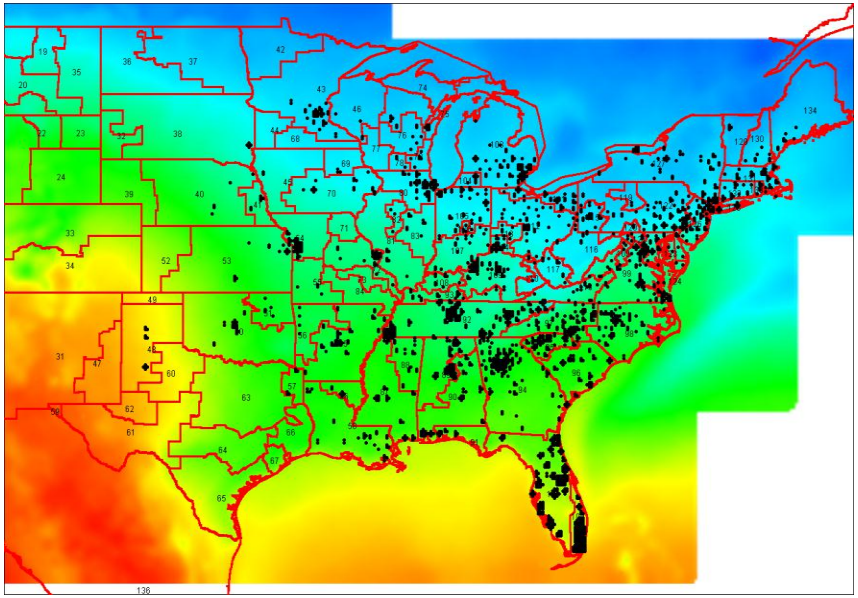
- **Sites selected from EWITS dataset plants based on ReEDS results**
- **Base Case - existing and planned plus best resources to meet state RPS requirements**
- **Existing plants in EWITS dataset are 'built out' to maximum capacity as identified by AWST**
  - Unable to scale those down to existing plant sizes as that would distort variability
  - Caused penetration in base case to be higher than existing capacity would suggest
  - May require some rework of base case

Solar Site Selection

- **ReEDS analysis again formed the basis for site selection for overall PV targets**
- **Unlike the wind data, the solar data did not exist for the project**
  - Next section discusses the method being used to simulate solar data
- **Based on regional analysis from ReEDS, sites where PV should be located were selected using simple rules**
- **Site selection would be 60% utility scale PV plants and 40% distributed rooftop PV**
- **PV locations over-specified by 20% to allow for variations in capacity factor and scenario flexibility**

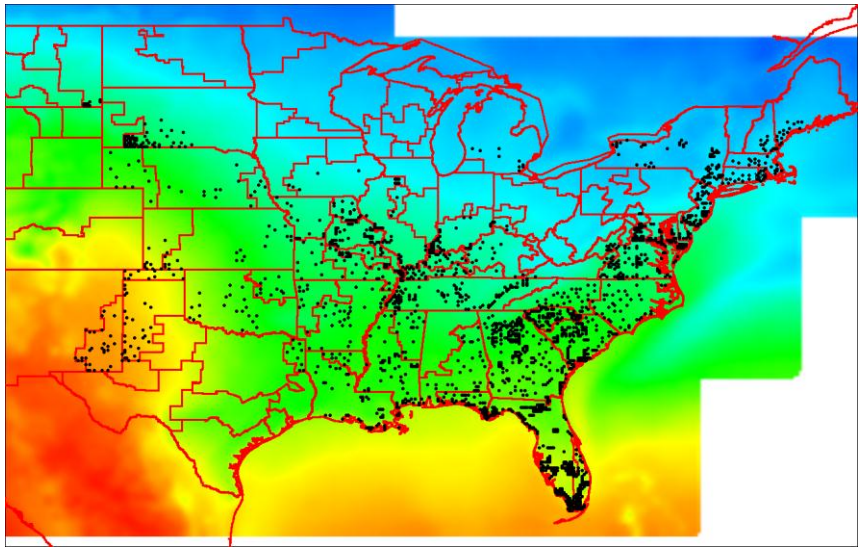
Rooftop Selection

- **Selection by county within each ReEDS region**
- **In a region, counties allocated capacity by population, proportion of state load**
  - Max of 1 kW/person except 1.5 kW/person in FL
  - Counties with small population excluded
  - Capacity is allocated surrounding the center of the county



Utility Scale PV

- Regional utility PV energy requirement calculated after rooftop complete
- Utility scale PV sites are non-distributed plants
- Selection was manual based on ReEDS results, NREL GHI resource map and estimated CFs
- 1925 plants ranging from 2 MW to 290 MW (avg. 73 MW)
- Final siting when profiles are completed and energy known



Solar Profiles

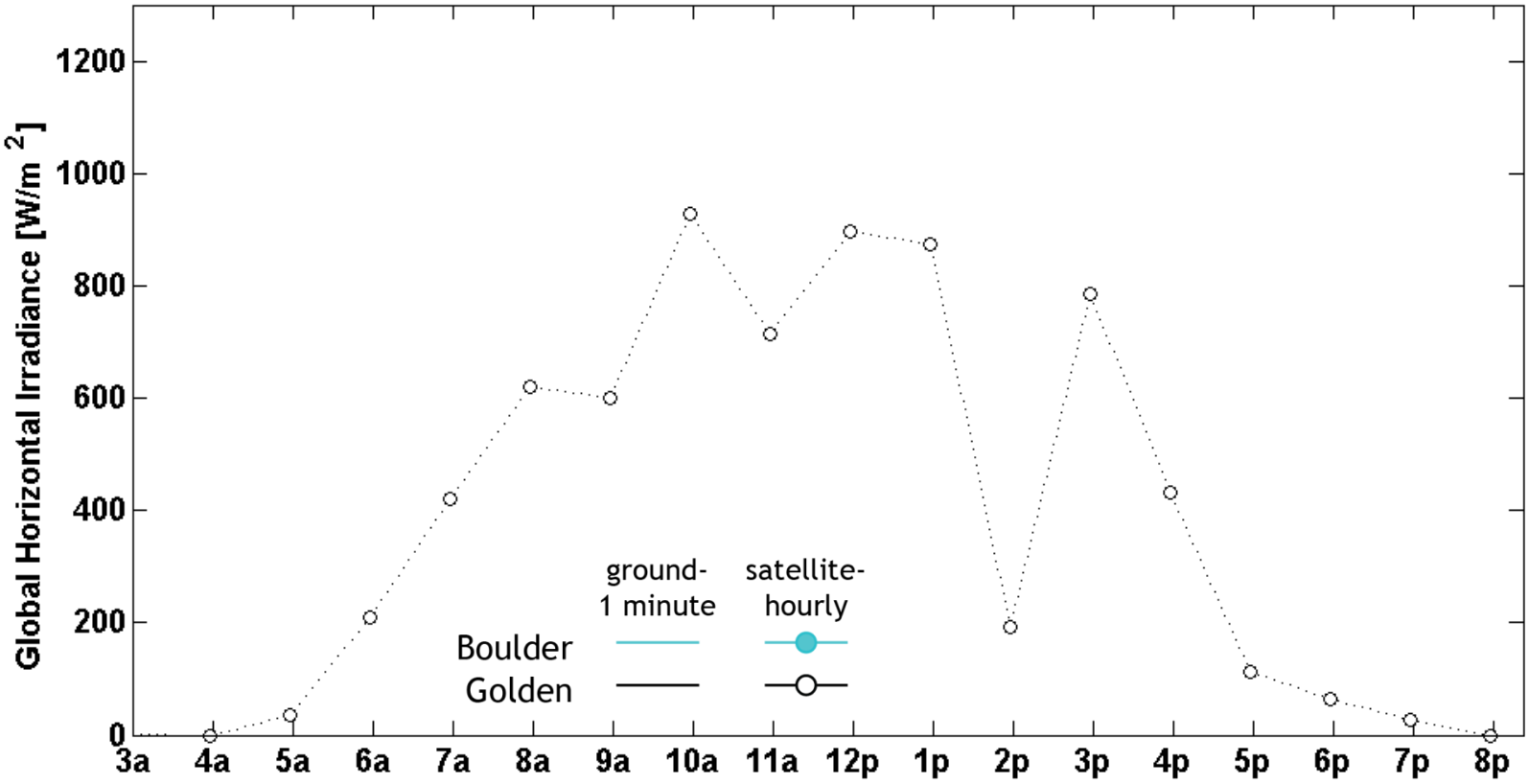
Solar Profiles

- **Solar Power Output Profiles:**
  - 1-minute, 10-km resolution
  - ~2000 rooftop sites
  - ~1500 utility sites
- **Key Characteristics:**
  - Appropriate number and size of power output ramps at each bus
  - Coincident power ramps occur at closely clustered nodes; rarely at nodes that are far apart
  - Sum of solar power over a region has appropriate ramps

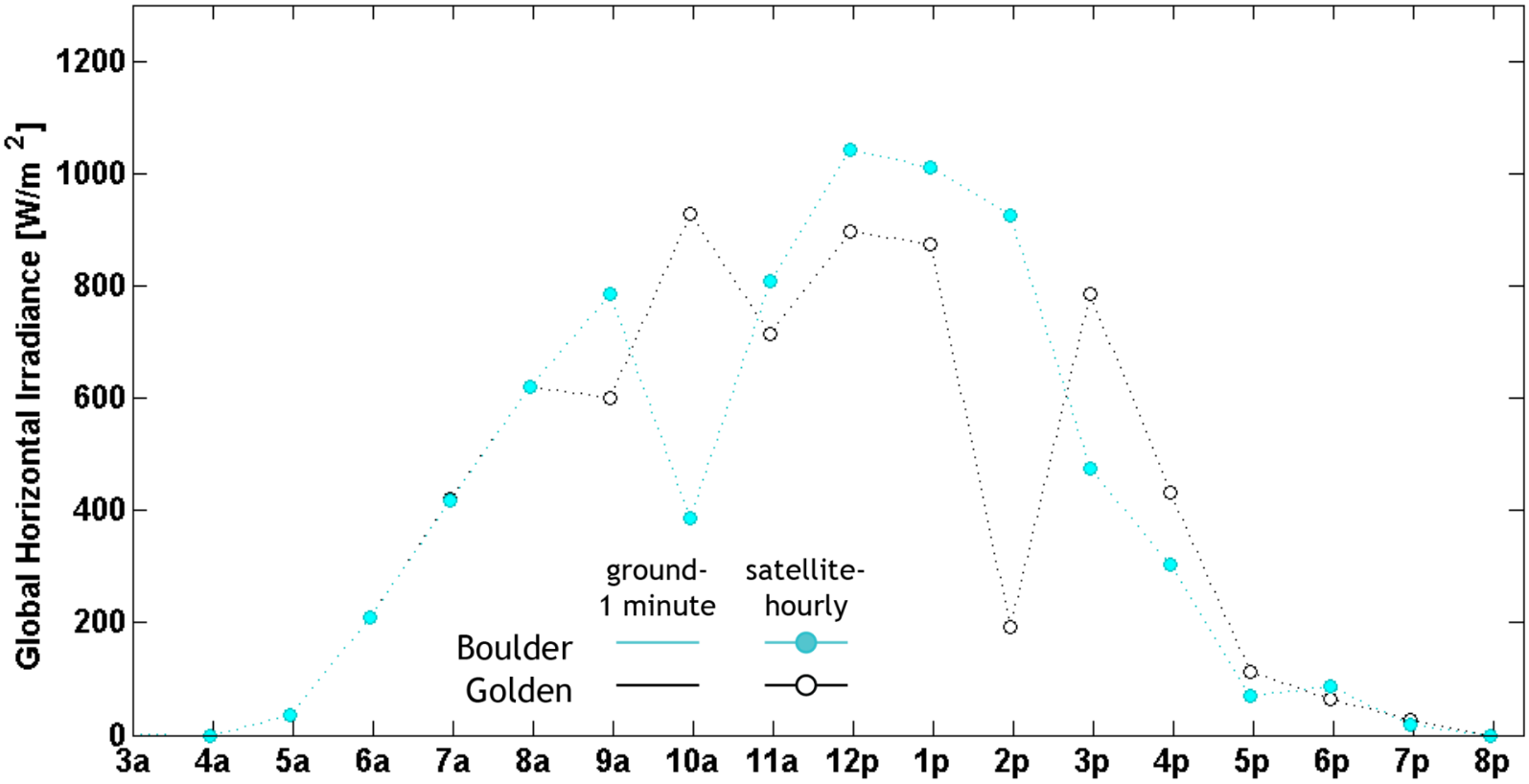
Solar Profiles

Andy Carter, View of clouds from above, South Africa.

Measured Solar Data



Measured Solar Data



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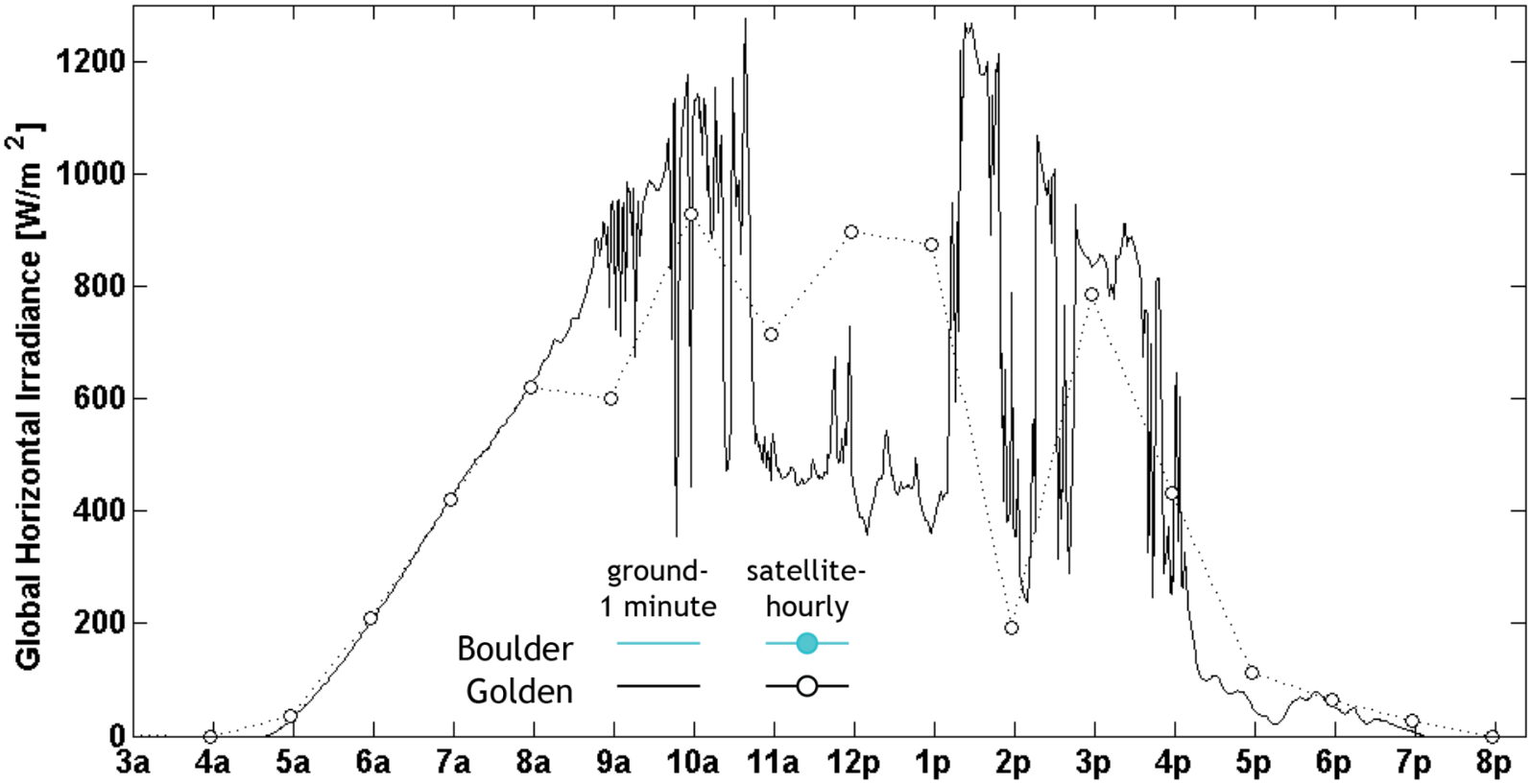
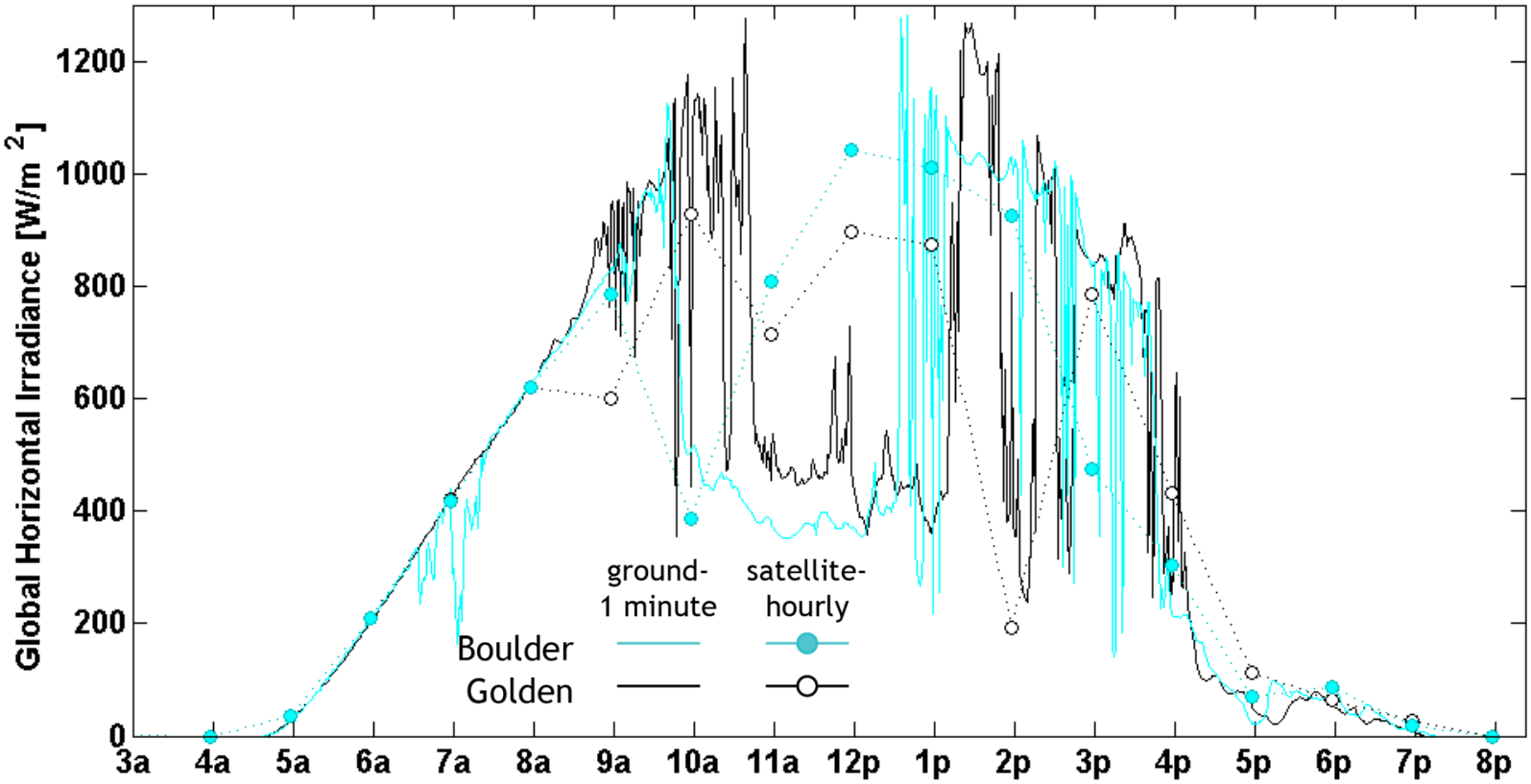
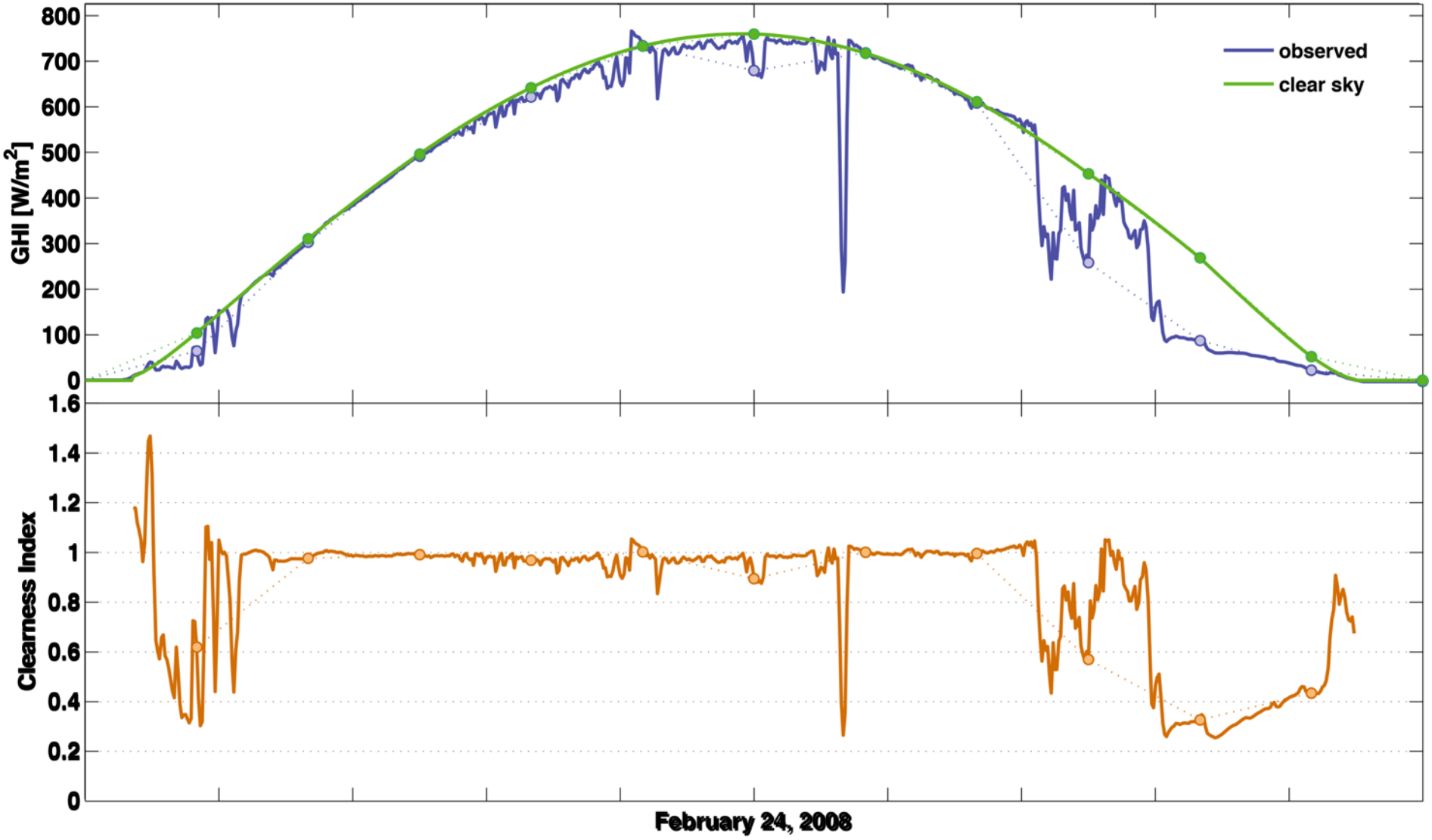


Measured Solar Data

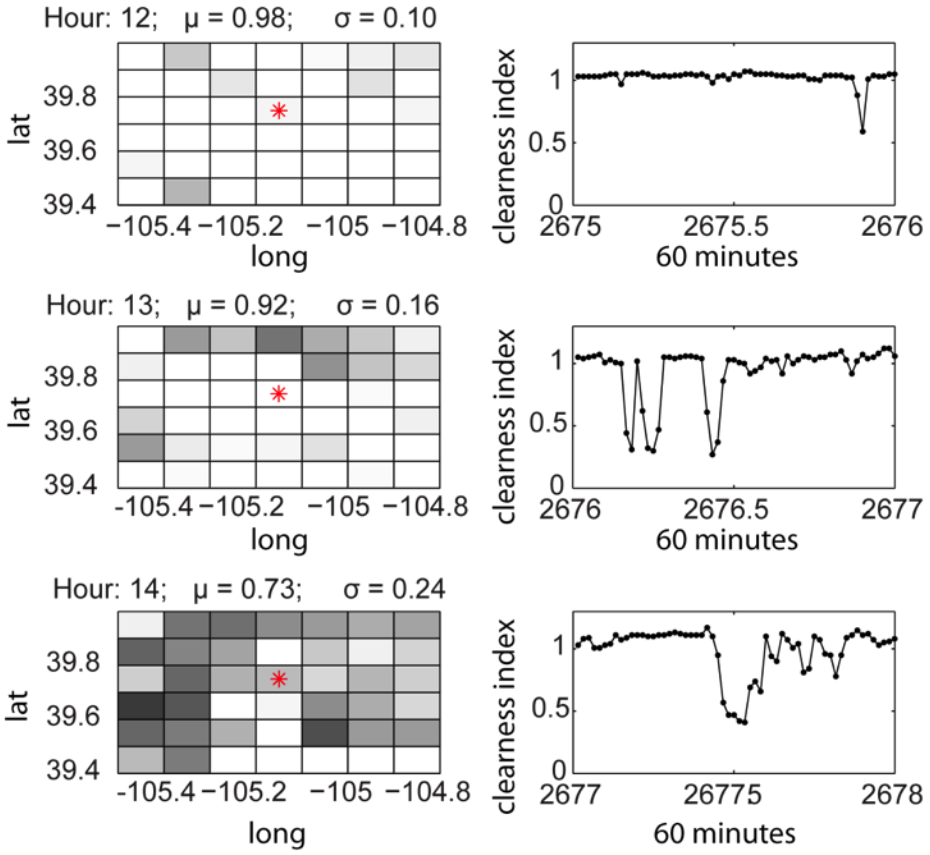


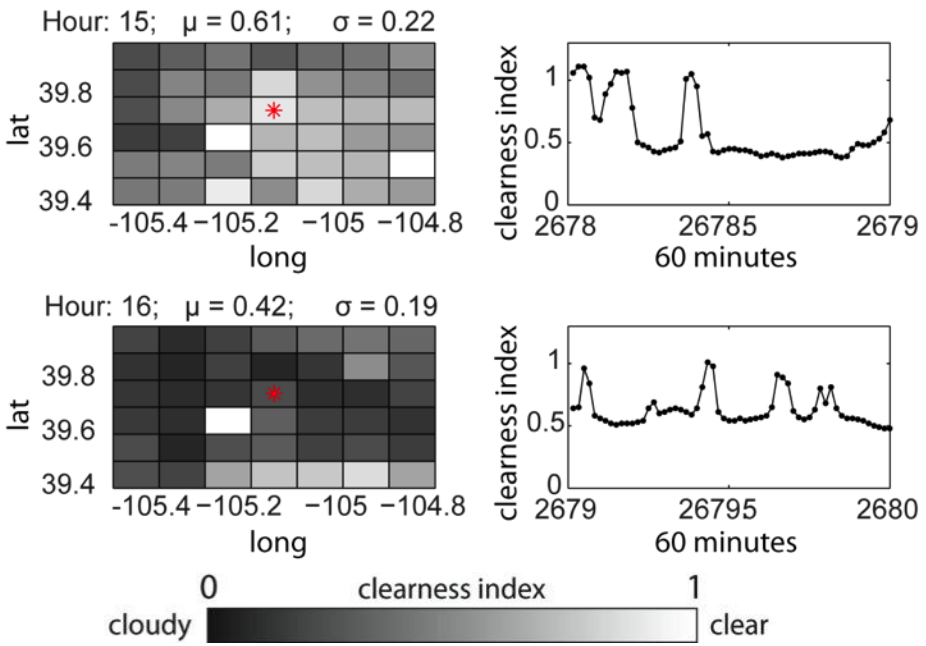
Clearness Index



Site Clearness Index Analysis

Spatial satellite data is used to calculate the relative proportions of cloud cover in an area for each hour. This data is related to the sub-hourly measurements of irradiance. These figures show five consecutive hours of aerial satellite data (left) and corresponding minutely ground-based irradiance data (right).





Solar Profiles

- Modeled sub-hour irradiance and solar power output data is appropriate for integration studies
- Using overlapping spatial variability statistics produces correlated temporal variability
- Aggregated modeled data has less ramps compared to a single site of modeled data
- Plea for data! We need measured irradiance or solar power data for sites throughout EI with temporal resolution less than ten minutes.

Discussion: Wind and Solar Profiles

What about the other generators?

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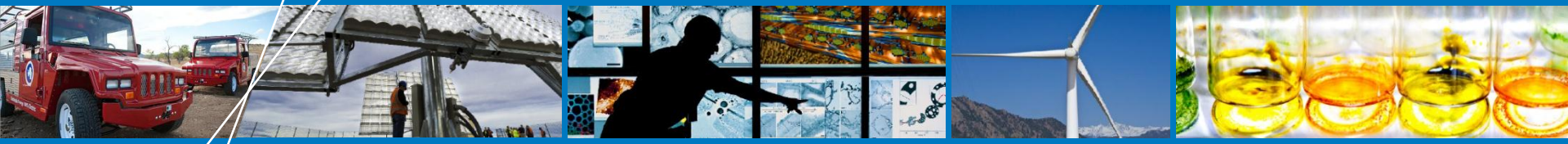
Generator Characteristics



Thermal Generator Characteristics

- **EIPC assumptions**
  - Part-load heat rate shapes
  - Min up/down times
  - Ramp rates
  - Forced and planned outage characteristics
- **Use EIPC assumptions except for:**
  - Unit-specific FLHR from EPA CEMS data
  - Startup, ramping, and VO&M costs from Intertek APTECH

EIPC Thermal Assumptions

Category	Marginal Heat Rate (% of Max Capacity / % of FLHR)				Minimum Up Time (Hours)	Minimum Down Time (Hours)	Startup Costs ($/MW)	Ramp Rate (MW/min)
	Step 1	Step 2	Step 3	Step 4				
CT	100% / 100%				1	1	0	
CC	50% / 113%	67%/ 75%	83% / 86%	100% / 100%	6	8	35	10
Coal_ST < 600MW	50% / 106%	75%/ 90%	100% / 100%		24	12	45	3
Coal_ST > 600MW	30% / 110%	50% / 93%	75% / 95%	100% / 100%	24	12	45	3
Oil/Gas_ST < 600MW	30% /110%	50% /90%	75% / 96%	100% / 100%	10	8	40	6
Oil/Gas_ST > 600MW	20% / 110%	50% / 95%	75% / 98%	100% / 100%	10	8	40	6
Nuclear					168	168		

Revisions

- **Intertek APTECH Data**
  - Statistical analysis of maintenance costs to quantify relative causes
    - Startup
    - Ramping
    - VO&M costs
  - Startup costs 2-3 times EIPC
  - Steady-state VO&M costs lower than EIPC
- **Ramp Rates**
  - EIPC assumption is independent of plant size
  - Revise to % of capacity/minute

Other Generation

- Hydro dispatch strategies and energy limits
- Generator characteristics for expanded capacity

Discussion: Generator Characteristics

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Transmission Modeling




Transmission Representation

- **Eastern Interconnect database currently contains:**
  - 62k nodes
  - 57k lines
  - Voltage levels from 400 V to 765 kV
- **Data came from MMWG**
- **Add expansion transmission capacity**
  - EIPC case?

Solve Time

- **Running a nodal model of the EI at a 5-minute interval presents significant computational challenges.**
  - WWSIS-2 took 6 days to solve
  - ERGIS may take_____?
- **Aggregate transmission into suitable zones**
  - One zone for each RTO/ISO or NERC Region
  - Multiple zones for each RTO/ISO or NERC Region

Seams Issues

- Flowgates?
- Hurdle rates?
- Interchange holding?

Discussion: Transmission Model

What is an operational impact analysis?

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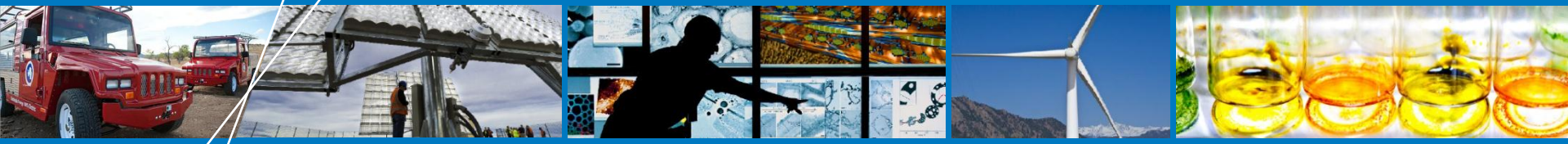
Variability and Uncertainty



Sources

- Wind and Solar
- Load
- Thermal Fleet
- Seams

Mitigation Options

- **Reserves**
  - Type
  - Quantity
  - Source
- **Commitment and Dispatch**
  - Day-ahead
  - 4-hour-ahead
  - Real-time
- **Seams Coordination**
  - Hourly interchange
  - 15-minute interchange
  - 5-minute interchange

Discussion: Variability and Uncertainty

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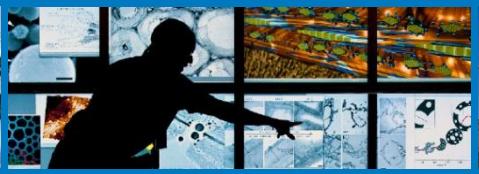
Next Steps

Industry Involvement

- **Technical Review Committee (TRC)**
  - Quarterly all-day in-person meetings
  - Review technical analysis of working groups
- **Working Groups**
  - Highly technical
  - Participate in many groups
  - 1-2 hour conference calls
  - Clustered

Working Groups

- **Potential Topics**
  - Generator characteristics
  - Wind and solar profiles
  - Transmission modeling
  - Thermal fleet expansion and retirement
  - Reserves analysis
  - Others ideas?

TRC Meetings

- **Where**
  - In the Eastern Interconnection
  - Close to airport hub
  - Suggestions, volunteers?
- **Future Meetings**
  - June 2013
  - September 2013
  - November/December 2013

Questions or Comments?

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